Fermilab Booster Collimator System

*Eric Prebys**
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*for N.V. Mokhov, A.I. Drozhdin, P.H. Kasper, J.R. Lackey, E.J. Prebys, R.C. Webber
FNAL, Batavia, IL 60510, USA

References:

- N.V. Mokhov, et al "Fermilab Booster Beam Collimation and Shielding", FERMILAB-Conf-03/087
- Bartoszek Engineering Website (http://www.bartoszekeng.com)

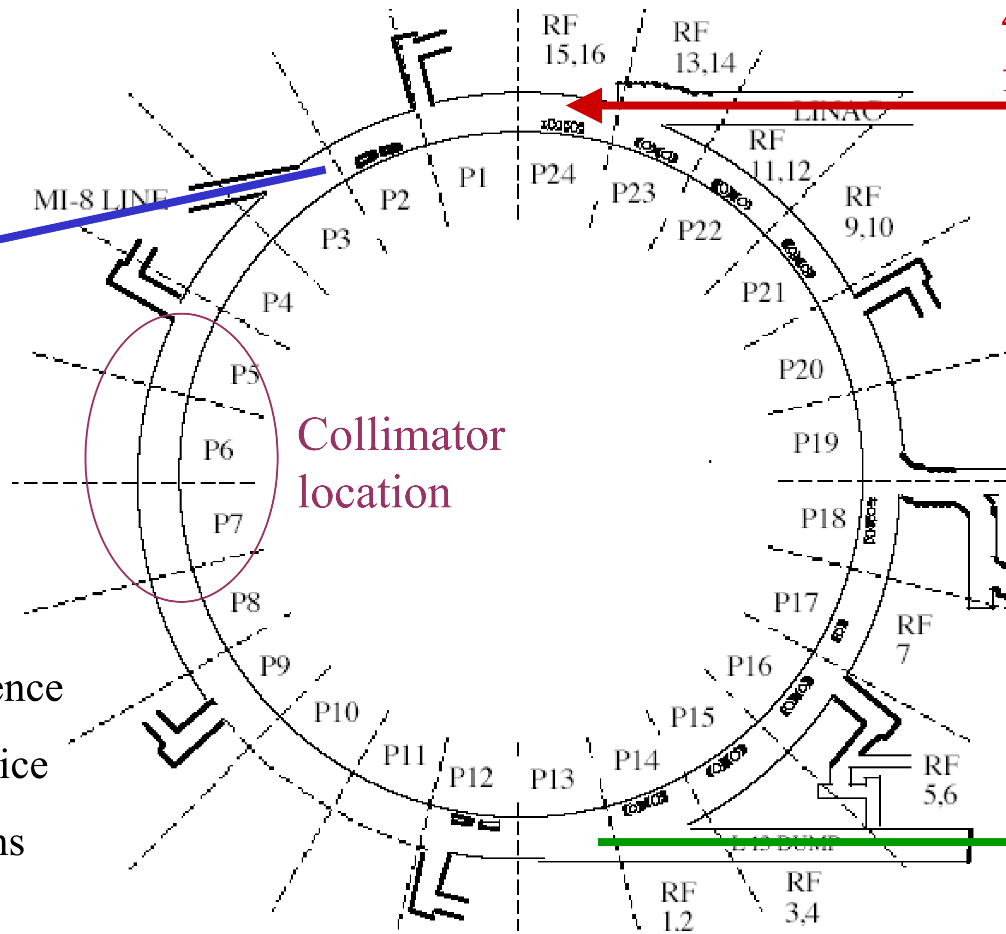
Outline

- Background and motivation
- Theory of operation
- First version
  - Preliminary results
  - Why this design was abandoned
- New version
  - Design considerations
  - Modeling
  - Details of design
- Schedule

Booster layout

8GeV Beam
to Main
Injector and
MiniBooNE

400 Mev Beam
from Linac

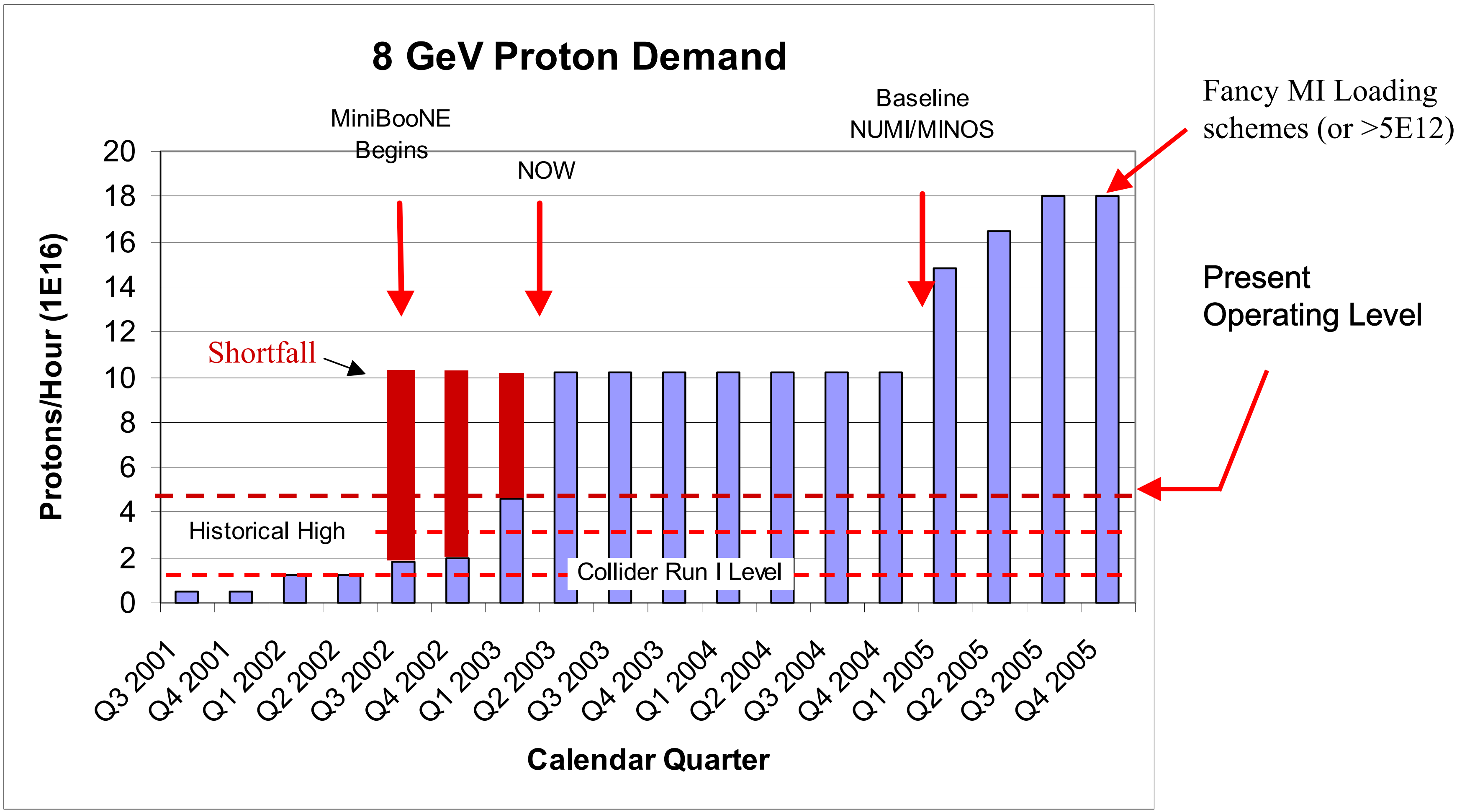


Old Main Ring
Extraction Line

Used for study cycles, RDF and "short batching"

- 472m in circumference
- 24-fold periodic lattice
- Each period contains 4 combined function magnets.
- Magnets cycle in a 15 Hz offset resonant circuit.

Demand for 8 GeV Protons



Limitations to Total Booster Flux

- Total protons per batch: 4.2E12 with linear beam loss, 5.5E12 max.
- Average rep rate of the machine:
  - Injection bump magnets (7.5Hz)
  - RF cavities (7.5Hz, maybe 15 w/cooling)
  - Kickers (15 Hz)
  - Extraction septa (was 2.5Hz, now 15Hz)
- Beam loss
  - Above ground:
    - Shielding
    - Occupancy class of Booster towers
  - Tunnel losses
    - Component damage
    - Activiation of high maintenance items (particularly RF cavities)

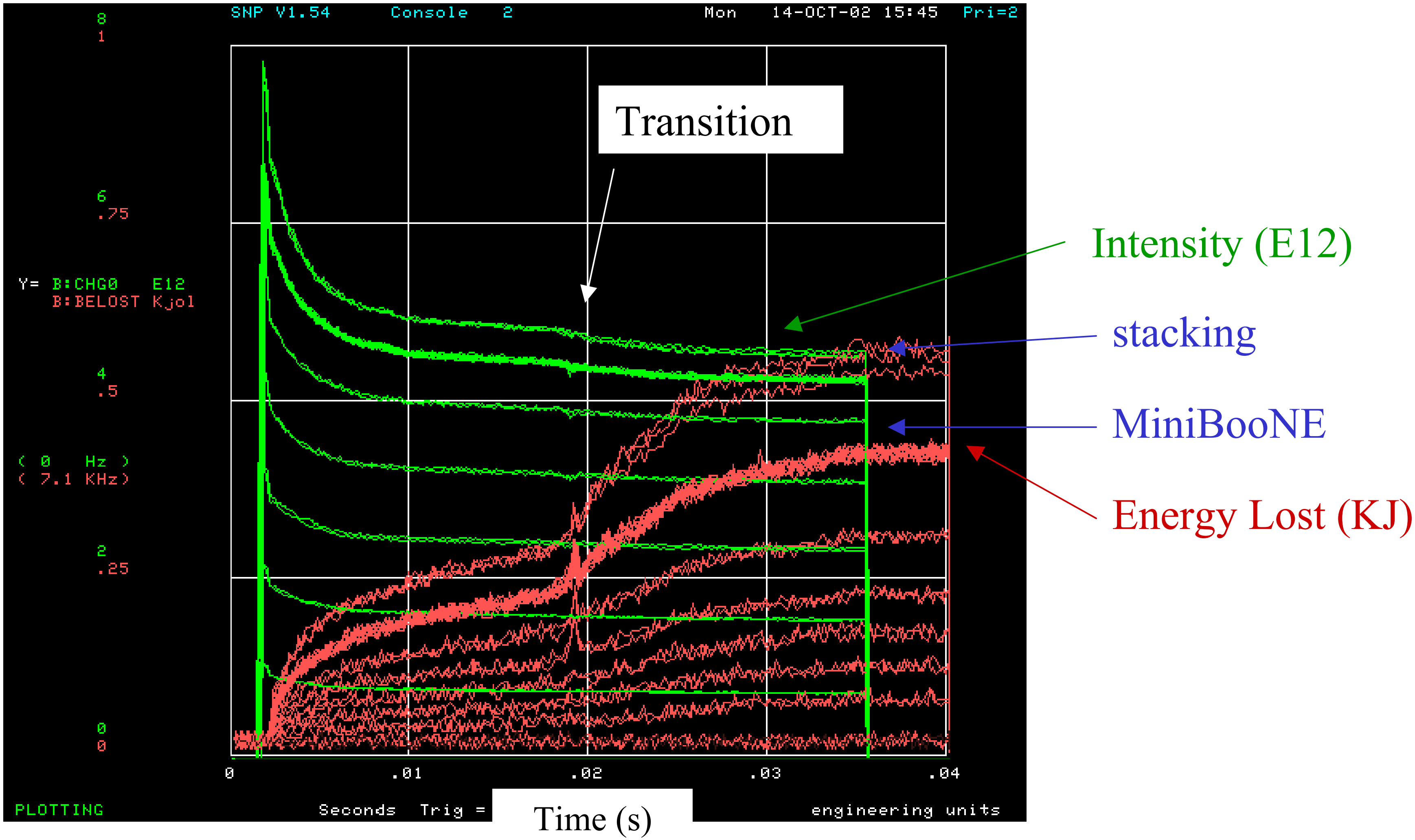
Of particular interest to NUMI

And stacking

Our biggest concern

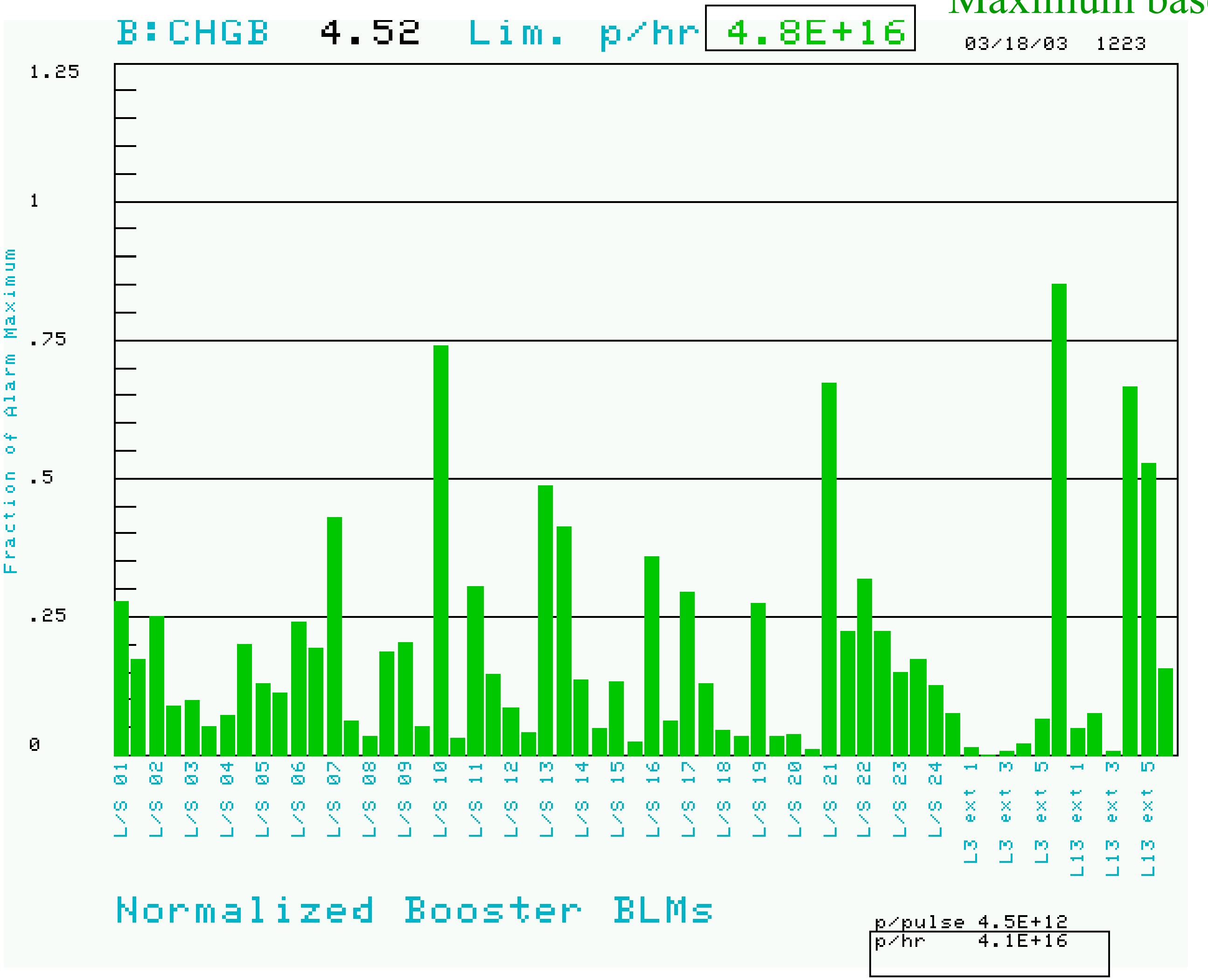
Typical Booster Cycle (2002)

Various Injected Intensities



Booster Losses (Normalized to Trip Point)

Maximum based on trip point



Also limit total booster average power loss (B:BPL5MA) to 400W.

Present rate

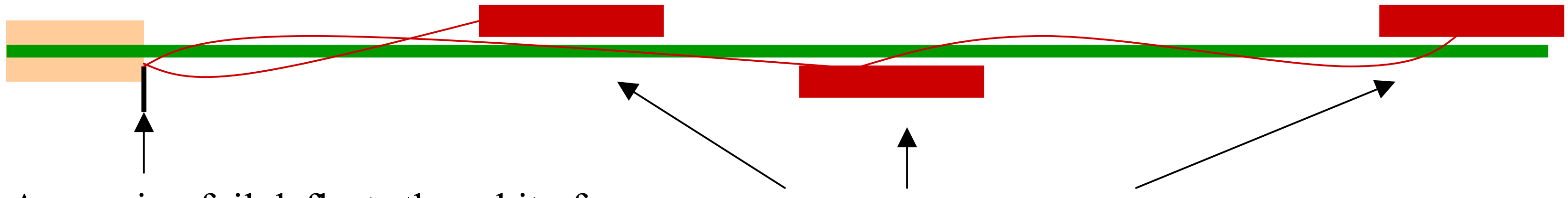
Bottom Line…

- The Booster now delivers protons at an average rate of about 5E16 pph.
- This supplies all the protons needed by antiproton production and about 45% of the MiniBooNE Baseline.
- Uncontrolled losses are about 400W, corresponding to the highest acceptable activation in the tunnel.
- To supply the full MiniBooNE request, increased antiproton production, and the protons requested by NuMI, the Booster might have to deliver as much as 2E17 pph.
- This must be done without a significant increase in *uncontrolled* losses.

$\Rightarrow$ *Need collimation system*

Booster Collimator System

Basic Idea…



A scraping foil deflects the orbit of halo particles…

…and they are absorbed by thick collimators in the next periods.

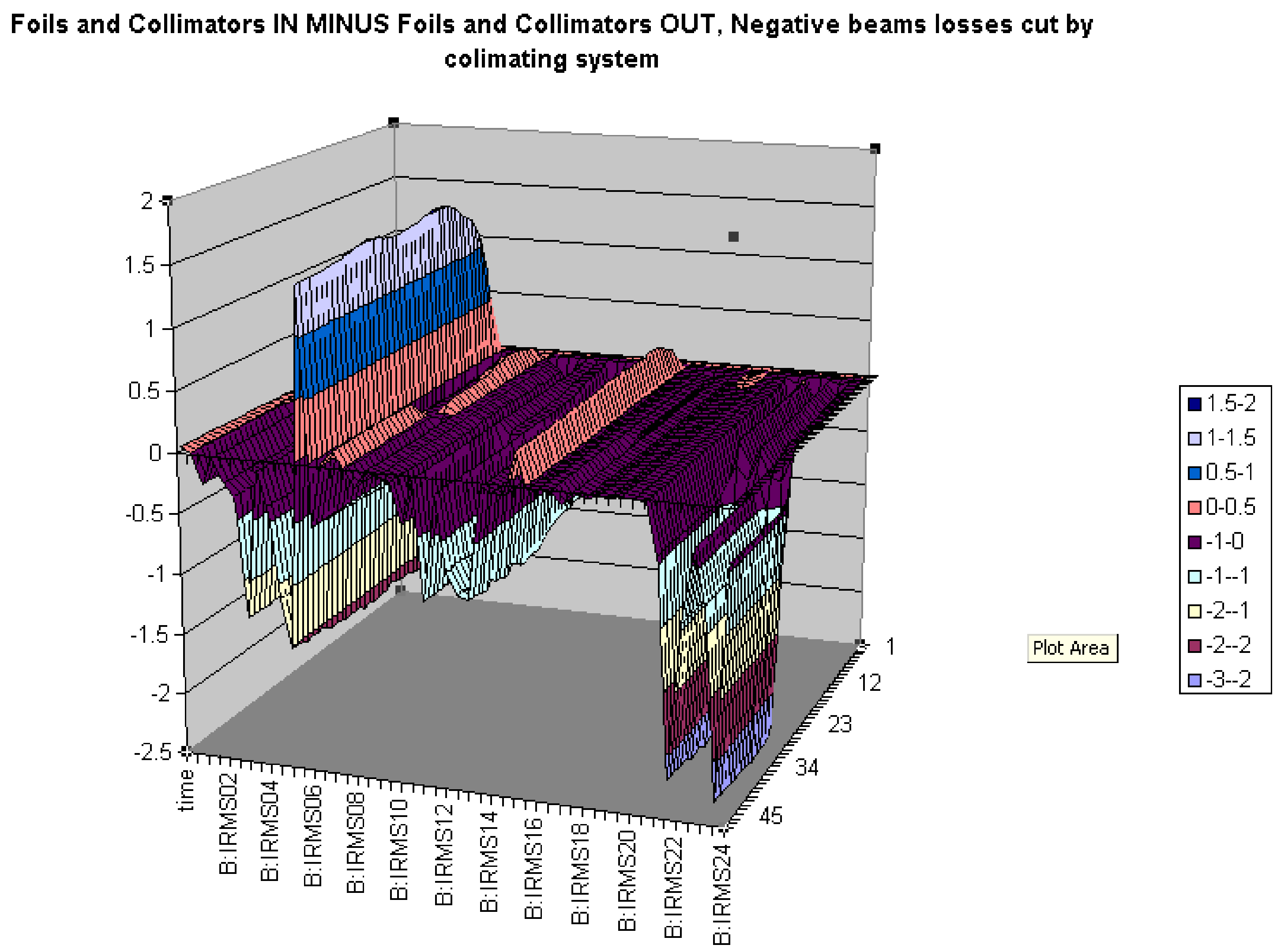
- Thin foils in Booster period 5 scatter beam in both planes.
- Period 6A collimator (37°H) intercepts horizontal beam.
- Period 6B collimator (20°V) intercepts vertical beam.
- Period 7 collimator (154°H,127°V) intercepts splash from period 6 collimators.
- **Goal: Absorb 99% percent of beam which hits primary collimator foil.**

First Version *(now called "prototype")*

End View

- Installed summer 2002.
- Plan was to stack steel shielding around it.
- Took some preliminary data, limited by Copper activation.

Preliminary Results from Prototype System



Why Design was Abandoned

- The extent of the shielding required was initially underestimated
  - Worry about radiation exposure budget of workers.
  - Awkward job. High risk of injury if working quickly.
- Unresolved heatloading issues.
- Serviceability an issue:
  - Motors, cables, cooling lines, vacuum flanges all inside shielding.
  - After extended operation, surface of collimator jaws ~100R/hr on contact.
  - No way to service interior components without exposing workers to these levels.
  - No realistic plan for removal of system!!

$\Rightarrow$ **Decided in Fall 2002 to remove and completely redesign**

(Note: Original design did *pass a review!)*

Key Features for New Design

- Collimator jaw *fixed* within monolithic shielding block.
- Entire assembly moves over range required.
- No aperture incursion when collimators in out position.
- *Nothing* important inside high radiation area.
- All vacuum seals, cables, motors, etc serviceable with acceptable radiation exposure to workers.
- Installation fairly quick (~2 days/collimator).
- In the event of catastrophic vacuum failure, fairly straightforward to remove entire assembly.

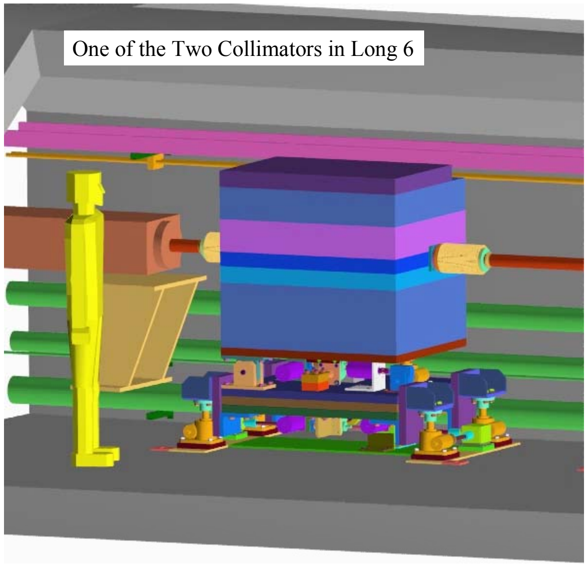
Collimator Modeling

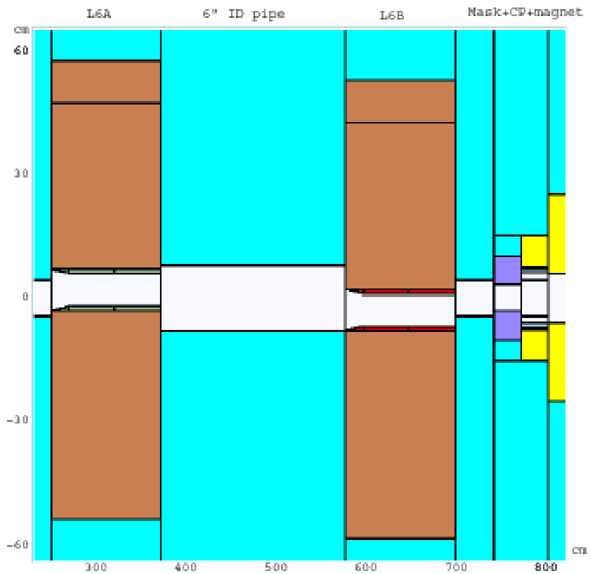
- We lack a *quantitative* model for beam halo and loss.
- Beam loss at primary collimator based on observed Booster loss patterns.
  - 30% @ 400 MeV
  - 2 % @ 8 GeV.
- Interaction with collimators modeled using MARS14.
- Particle transport done with STRUCT based on *ideal* Booster lattice.
- Thermal calculations done using ANSYS, starting with MARS energy deposition.

Shielding Constraints

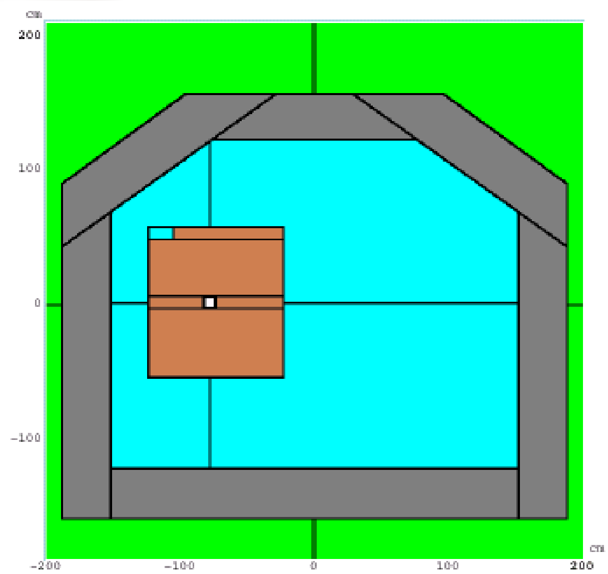
- Assume maximum proton demand: 5E12 protons @ 10Hz (Stacking, MiniBooNE+NuMI).
- Limit surface dose (13.5 feet of dirt) to 5 mR/hr.
- Keep activation in sump water to within surface discharge limits -> "star density" of 4000 $cm^{-3}s^{-1}$ (ground water not an issue).
- Keep activation at the surface of shielding to within acceptable limits for servicing after 30 days running/1 day cool-off.
- Geometric constraints of the tunnel.

System as Modeled



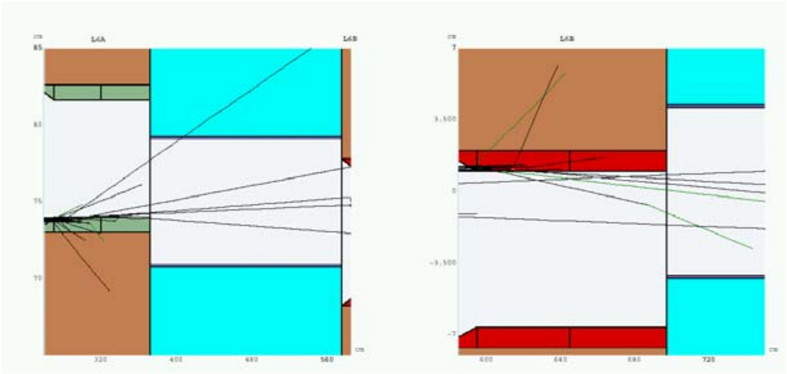


Period 6 Side View



End View

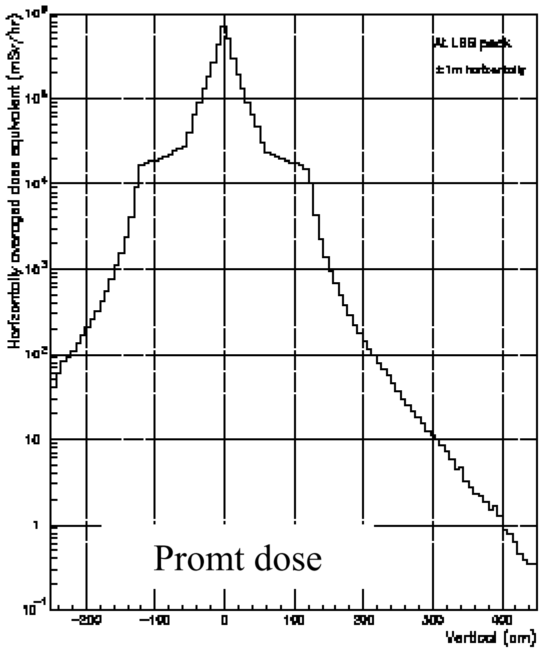
- 3"x3" aperture
- Stainless steel collimator integrated into steel shielding.
- Total length: 48"
- Width: 43.5"
- Height: 43.5"

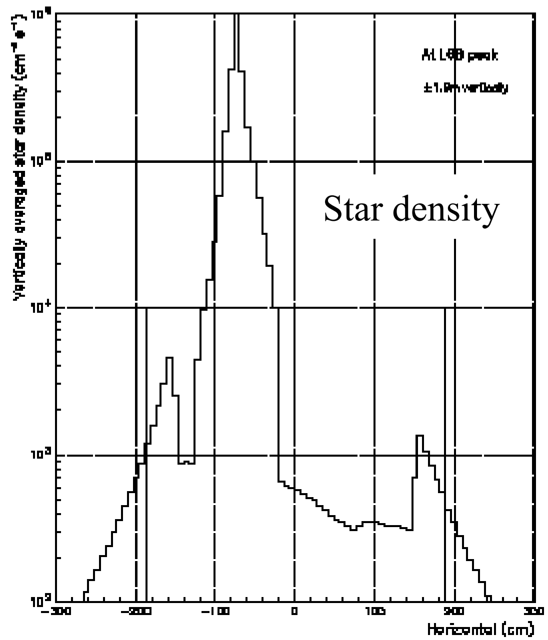


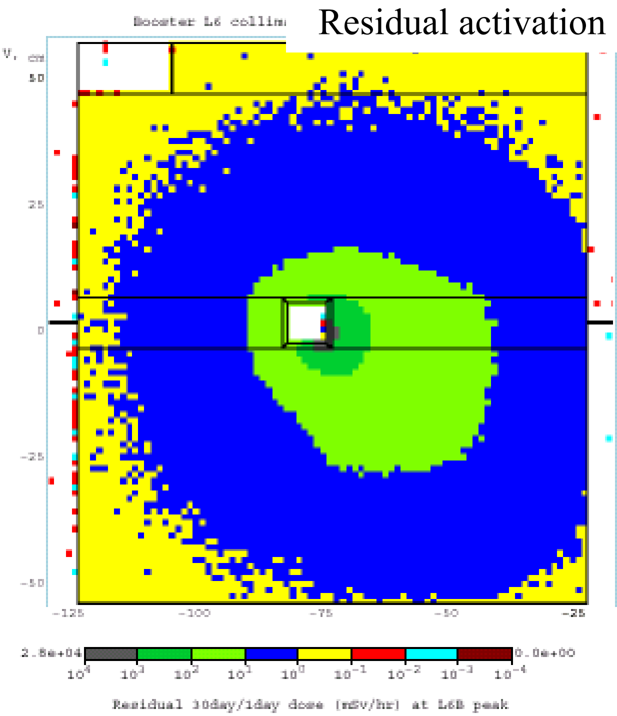
Results of Modeling

- At 400 MeV (30% total loss):
  - 13% in L6A
  - 7% in L6B
  - 10% in L7
- At 8 GeV (2% total loss):
  - .7% in L6A
  - .3% in L6B
  - 1% in L7
- Ringwide losses reduced to average of .1 W/m with peaks to 1 W/m.

Results of Modeling





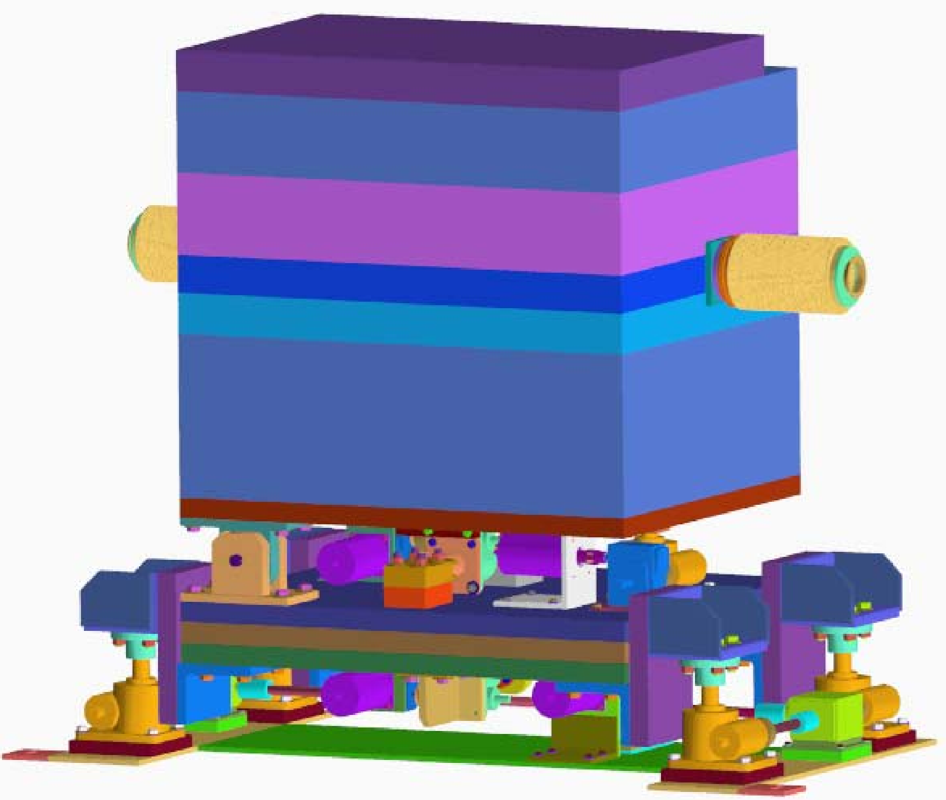


Description	Limit	Model
Dose at surface	5 mR/hr	1.25 mR/hr
Sump water activation (star density)	4000 $cm^{-3}s^{-1}$	1163 $cm^{-3}s^{-1}$
Residual Activation (30 day run/1 day cool)	“Reasonable”	Shielding: 100 mR/hr* Beam pipe: 4000 mR/hr (end of collimator) Corrector package: 4000 mR/hr

Thermal Issues

- The integration of the collimator jaws into the shielding aids in heat dissipation.
- Heat load calculated using ANSYS starting with the energy deposition from MARS.
- Without active cooling:
  - Maximum steady-state temperature: 60°C
  - No problems from differential expansion.
  - Collimators OK up the total absorption of 25 8 GeV pulses over 2 seconds (physically impossible).

Collimator Motion



- All collimators identical
- 3” square beampipe.
- Allow any edgeto move from completely out to the beam center (→±1.5” horizontal and vertical).
- Independent ±10 mrad pitch and yaw motion to align collimator jaw to beam.
- Will move over useful range within 5 min.

Status and Schedule

- Design complete
- Passed review *(serious one this time??)*
- Time critical parts ordered.
- Fabrication beginning.
- Will be ready for the Fermilab summer shutdown (July 28, 2003).

Lingering Issues

- Primary collimator thickness:
  - Model assumed .15 mm Carbon at injection and 5.4 mm at 8 GeV (.003mm to .1 mm Tungsten).
  - Existing system uses fixed .3 mm Carbon.
  - Considering upgraded design with rotating wedge.
- Beam position issues:
  - Beam radius decreases with energy.
  - Must move beam to compensate (hardware in place. Software must be modified).
- Lattice issues:
  - Model assumed more or less ideal lattice.
  - We have known injection lattice problems caused by our extraction dogleg magnets.
  - We don’t think it’s an issue, but need to double-check.